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Art. XVI.—*The Structural Features of the Silurian Rocks in the Melbourne District.*

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(With Plates IX., X.)

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Introduction.

Early in 1929, it was suggested by Professor Skeats that a detailed map of the folds in the Silurian around Melbourne might prove interesting in view of the fact that the rocks of this district lie in what is usually known as a "crush zone." An attempt has been made to locate the main axial lines, and as many as possible of the minor folds which are so common in the area. The difficulty of the work lay in the complete lack of any kind of outcrop in many of the suburbs, while in others the only exposures of rocks found were small and widely separated road cuttings. On this account there are many gaps in the records of the axial lines, and the positions of some as shown on the accompanying map have been judged largely from better defined folds near them.

Previous Work.

The quarter-sheets of the district (1) compiled by the Geological Survey were of great use since they give the dip and strike of rocks in many places where the rocks are now completely hidden. On the other hand, the Survey had few cuttings to work from, and their dips as judged from surface outcrops alone have not always been found correct.

Dr. N. R. Junner (2) in his work on Diamond Creek has mapped some structural features to the north of the city, and he has located the positions of the Templestowe anticline, Greensborough syncline, and Dry Creek anticline. He discussed the contortion of the western limb of the Templestowe anticline, mainly in connection with the Diamond Creek mine.

Mr. J. T. Jutson (3) while working on the Warrandyte goldfield has mapped the axial lines from the Templestowe anticline to the east. He mentions the crushing of the western limb of the Templestowe fold, but has dealt mainly with the structure of the Warrandyte anticline.

No attempt has been made previously to work out the details of the folding in the districts near Melbourne.

General Structure.

The Silurian rocks of the area are interbedded mudstones, sandstones, and shales, often with iron oxide deposited along the

bedding. The beds vary in colour and texture, but it is impossible to pick out characteristic bands by which amount of folding or faulting might be judged. The rocks have been compressed into folds whose axes run fairly parallel in the Melbourne area. The strike of these axes varies from N.20-25°E. to N.35°E. in the southern part of the area.

In the eastern suburbs from Box Hill to Oakleigh the folds persist over the whole length of the area studied, and show a considerable thickness of rocks in their limbs. Towards the city, however, the major axes appear to lie much closer together, although they still persist over long distances. The dips of the rocks in the two limbs vary, but it has been found that from the Blackburn fold to the City the western limbs of the main anticlines show the steeper dip, giving a list of the axial plane to the east. Jutson states that at Warrandyte, the axial plane of the main anticline lists to the west. He has found that five normal folds which occur further south have been compressed at Warrandyte into one great arch with minor puckers on its crest. The Warrandyte zone is therefore one of intense compression, and its features do not resemble those of the city area.

Apparently the compression increases from the Blackburn anticline westward to the City, since the folds lie closer together there. This is shown also by the presence of numerous minor folds with axes parallel to the major lines. These minor folds show relatively small thicknesses of rocks in their limbs, and are usually pitching strongly, accounting for the fact that they are not persistent along the length of the fold. They are generally local puckers consisting of an anticline and syncline close together, although separated by a much greater distance from the next pucker.

It has always been assumed that the small folds occur on the crests of the main anticlines. While this appears to be the case at Warrandyte, the writer has found that the minor folds in the Melbourne area occur not at the crests of the anticlines, but along their western limbs. Evidently in such a series of folds as occur here, the rocks of the steeper dipping limb are subjected to greater compression than the rocks of the opposite limb. The type of structure is shown in Section A, Text-fig. 1. A similar structure is figured by Hobbs in "Earth Evolution and its Facial Expression," but he gives it merely as a typical geological section, and does not discuss the characters of the folds.

Reversed faulting is very common in the zones of intense folding, but the faults have generally an unusually small angle of hade and do not seem to have affected the positions of the axial lines to any great extent. The faults show strikes closely parallel to the strike of the beds, but no attempt has been made to map them since in the absence of characteristic beds it is impossible to judge the displacements they have caused. The basic dykes so common in the area frequently occur along these fault planes.

Associated with some of the crushed areas, small quartz veins have been found. They form a network suggesting the passage of solutions along fine crevices in the shattered rock, and no veins of any great size have been found. Since the crush zones represent areas of intense local compression, it would not be expected that any large quartz veins would be found such as occur in the zones of tensional stress at the axes of the anticlines.

Details of Folds.

The Blackburn anticline, Bulleen syncline, and Templestowe anticline named by Jutson persist further south than his map shows them, the first two being traced to Oakleigh and the last to Tooronga. Very little work has been done as far east as the Blackburn fold, but on the western limb of the Templestowe anticline puckers occur, well shown in a brick pit near Camberwell Road. Both Junner and Jutson mention the contortion of the western limb of this fold. Each of the succeeding anticlines traced has been found to show the same folding of the western limb at some place along its length. With most of the folds the structure is not very complicated, being in the form of one or two small puckers only. With at least one anticline, however, the one which passes through Studley Park, the rocks have been crushed into numerous small folds, and are greatly contorted and faulted. The most southerly outcrop of this crush zone is indicated by the dips on the south bank of the Yarra east of Princes Bridge, as shown on Quarter Sheet No. 1, S.E. Further north in Studley Park excellent sections of crushed rocks are to be found. To the north of this, the anticline is covered by the Darebin Creek basalt, suggesting that the pre-basaltic stream found the crushed rocks a line of weakness along which it carved its valley.

The road down to Johnston Street Bridge shows two minor puckers pitching strongly south. Between the lower of these and the next syncline occurs a shattered area shown in Section B, Text-fig. 1, where the folds are sometimes only a few feet apart and where reversed faulting is very common. At Dight's Falls there occurs a distinctive thickly bedded sandstone which appears to dip north-east. It seems probable that this sandstone band may be correlated with a well marked syncline which occurs just across the neck of the meander, and that its apparent dip

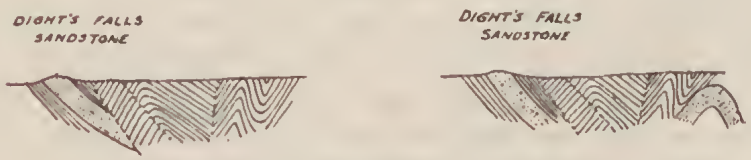


Fig. 2—Possible types of structure in the Studley Park crush zone.

north-east is due to a strong northerly pitch. The fact that the westerly dipping arm does not appear may be due to the complicated faulting of the rocks to the east having the total effect of a reversed fault hading east, in which case the sandstone would have been lost by erosion; or the folding may have been such that the sandstone remained below the surface to the east. (Fig. 2.) In either case it seems likely that the extreme contortion of the rocks to the east is due to their having been thrust in some way against the resistant sandstone. On account of the northerly pitch of this bed, it does not outcrop to the north, and to the north the shattered zone also is absent, the rocks along the river bank south of Alphington having a uniform westerly dip.

The local crushed areas occur in many other places near the City, at Church Street Bridge, Heyington cutting, Jolimont cutting, and in other parts. In the Victoria Bridge road cutting an excellent outcrop of an anticline occurs. This shows a greater thickness of rocks in the eastern limb than is usual with a minor fold, yet it is about ten chains west of the major axial line as judged from outcrops to the north and south. No other outcrops could be found in the district, so it is impossible to judge whether the anticline represents a minor pucker larger than usual, or whether the major axis has been displaced by faulting. The area is one in which several reversed faults occur, some with quite a large angle of hade. The strong southerly pitch and the almost north to south strike of the axis are usual features of minor folds, but both might have been caused by faulting.

In his paper on Diamond Creek, Junner speaks of a sharp anticlinal axis at Dry Creek, north of Greensborough. He states that the axial plane lists to the east at 70°, and continues: "Going further east from here along the E-W bend of the Plenty R., several small anticlines and synclines occur close together." This is obviously a slip, since the E-W bend of the Plenty lies to the west of Dry Creek. The writer has located these small folds, and they occur down the western limb of the Dry Creek anticline.

Summary and Conclusion.

Mapping of the available outcrops of the Silurian rocks in the eastern suburbs of Melbourne has shown the axes of the folds to run fairly parallel across the area, striking approximately N.25°E. The axes of the major folds lie closer together as the City is approached, and greater compression is shown also by the numerous minor puckers and small crush zones which appear. These outcrop down the western limb of the anticlines, and this limb has been found to show the greater dip, indicating that greater compression acts on the steeper dipping limb. Small quartz veins are associated with the crush zones, but large reefs are confined to the axes of the anticlines. The details of the more important folds in the area have been discussed.

In conclusion, I would like to express my gratitude to Dr. Summers for his unceasing interest and assistance throughout the year. I would also like to thank Mr. J. S. Mann for his help in the preparation of my map and sections.

References to Literature.

1. Quarter Sheet No. 1, NE. and SE., Geol. Surv. Vic.
2. N. R. Junner. General and Mining Geology of the Diamond Creek Area. *Proc. Roy. Soc. Vic.*, n.s., xxv. (2), 1913.
3. J. T. Jutson. The Structure and General Geology of the Warrandyte Goldfield and Adjacent Country. *Ibid.*, n.s., xxiii. (2), 1910.

Description of Plates.

Plate IX.

Structural map of the area studied showing major axial lines. The dips in the crushed zones have not been marked in. C.Z.—Studley Park crush zone shown in Text-fig. 1. Section B. V.—Victoria Bridge anticline.

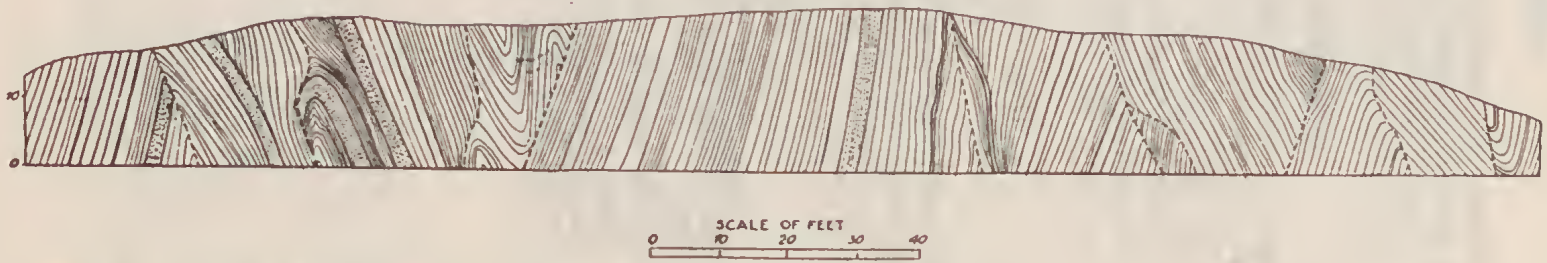
Plate X.

Photographs of rocks in Studley Park crush zone, on road cutting from Johnston Street Bridge to Dight's Falls.

Fig. 1.—An incompetent shale crumpled under a resistant sandstone.

Fig. 2.—An anticline and syncline crushed close together, and faulted along their axes.

SECTION A.—Section line AB on map, Plate IX. To show relief the vertical scale was exaggerated, but since the width of the beds are conventional only, the dips of the beds have not been altered to correspond.



SECTION B.—Sketch section of cutting from Johnston Street Bridge to Dight's falls, vertical and horizontal scales the same. Dotted beds represent resistant sandstones against which shales have been crushed.

FIG. 1.